Appendix A-4
Hydrogen as a Rocket Fuel

By the end of World War II, the major properties of liquid hydrogen were well established. The technique for its liquefaction, first developed by James Dewar in the nineteenth century, was refined but remained basically the same. Hydrogen liquefaction equipment and capacity remained small because the only demand was for research investigations in government laboratories and universities.

Liquid hydrogen was one of the first liquid rocket fuels proposed, but it was abandoned because of its low density, low availability, and handling hazards. Gaseous hydrogen technology, including its use as a fuel, was developed in association with dirigibles, but those airships were abandoned. Walter Thiel experimented with liquid hydrogen–liquid oxygen in a rocket engine in Germany in the late 1930s, but he experienced difficulties with leakage. In general, the experiences in using either gaseous or liquid hydrogen in flight applications were not favorable. To understand why, let us note the desirable characteristics of rocket fuels and evaluate hydrogen against each criterion.

High exhaust velocity. This is the single most important performance goal and is related to the heat of combustion of the fuel and the molecular mass of the combustion products. The importance of having a high exhaust velocity was first expressed by Tsiolkovskiy in the early 1900s. Hydrogen surpasses all other chemical fuels in exhaust velocity, and were this the only consideration, it would have been chosen and used in preference to other fuels long ago.

High fuel density. The second most important characteristic is a high fuel density, for this increases the mass ratio of a vehicle and increases its range or payload capability. Higher density also reduces drag during flight through the atmosphere, by allowing smaller and lighter tanks. Unfortunately, hydrogen has the lowest density of all fuels, a characteristic most responsible for Tsiolkovskiy's—and others following him—abandoning the consideration of hydrogen as a flight fuel. Oberth, however, believed correctly that this handicap could be overcome by very light construction techniques and by using hydrogen only in the upper stages of a multistage rocket.

Desirable cooling characteristics. These include a relatively low combustion temperature to lessen the heat flow into the engine walls, and fuel characteristics of high thermal stability and specific heat so that it can be effectively used as a regenerative coolant. In addition, a low vapor pressure or low critical pressure keeps the fuel-coolant from boiling or existing as both liquid and gas in coolant passages—an

undesirable situation. Hydrogen scores well on these characteristics (except low vapor pressure) but there is no evidence that anyone considered or experimented with liquid hydrogen as a coolant prior to 1945—probably because nobody got beyond hydrogen's undesirable characteristics.*

High reaction rate. Rapid reaction of fuel and oxidizer over a wide range of conditions is advantageous in converting the energy content of a chemical fuel to heat in a minimum volume. Hydrogen's high flame speed, low ignition energy, and wide flammability limits—all advantages—have been known a long time but were not fully appreciated until after 1945.

Desirable handling and storage characteristics. An ideal fuel for handling and storage has a low vapor pressure, low freezing point, high shock stability, high ignition energy, and is nontoxic and noncorrosive. Hydrogen scores poorly on these desirable characteristics with its very low temperature (high vapor pressure), low ignition energy, and wide flammability-explosion limits.

Available in quantity. Hydrogen scored low on availability before World War II primarily because the only demand was for small quantities for scientific research. Gaseous hydrogen and the technology for its liquefaction were available, however.

From these six general considerations of fuels, it can be seen that hydrogen's properties represented the extremes in both desirable and undesirable characteristics and offered a fitting challenge to those interested in exploring the potential of new fuels.

*Robert Goddard has been credited with the idea of regenerative cooling with liquid hydrogen, but the author questions this based on research for this book.